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MAPS AND MAP MAKING.*

BY

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The making of maps presupposes that information has been gathered with reference to that portion of the earth's surface to be pictured graphically. This accumulation of information usually goes through several great stages before the completed map, the object aimed at, is accomplished.

The first stage is that of discovery and exploration, when the character and apparent extent of the country are noted and observations, more or less crude, are made in an effort to fix the latitude and longitude (the position on the earth) of the country through which the explorer may be hastily passing. This phase, continued through the efforts of many men and usually covering a great number of years, during which time the country is opened up and industries started, gradually leads to the next step, or the Reconnaissance Survey of the region. This work is conducted with more care, and reconciles the many and often conflicting results of the early explorers. As the country is developed through increase of population and the consequent growth of trade and business enterprise, there is a demand for a more detailed map. As a result of this demand we eventually have a scientifically correct survey of the country on a convenient scale, which would form a reliable and suitable base for the still more detailed work for all other special purposes, such as railway building and public improvements.

The most conspicuous figures from among a host of other early philosophers, mathematicians, and geographers, each in his time

* Figs. 1, 2, 3 and 7 are taken from Appendix No. 15, U. S. Coast and Geodetic Survey.

standing as a milestone along the pathway of geographic knowledge and of map-making, may be named in the order in which they lived, together with the most important contribution of each to that knowledge.

Pythagoras, who flourished about 580 B. C., raised mathematics to the rank of a science, and devoted himself to the purely geometric phase of the subject. Herodotus lived about a century later. In his history, which included geography, he transmitted to posterity an account of the world as it was known in his day. Pytheas, who lived about 326 B. C., was the first to apply astronomy to geography. Dicaearchus, about 310 B. C., a pupil of Aristotle, made the first approach to a projection by dividing the then known world into a northern and a southern half by a straight line, thus drawing the first parallel of latitude. Hipparchus, who lived about 150 B. C., introduced among the Greeks the earlier Babylonian divisions of time and space, and of the circle into 360 degrees, with the subdivision of 60 minutes and 60 seconds and the corresponding divisions of the hour. He divided the equator and other great circles into 360 parts or degrees, and through these divisions he drew other circles, to which he was the first to give the technical name meridians. By thus employing two sets of reference lines, covering the surface of the earth with a network of parallels of latitude and meridians of longitude, he advanced the science of geography to a plane far in advance of his time, and laid the foundation for map-making for all time. It was he who pointed out, three centuries before the time of Ptolemy, that the only way to construct a really trustworthy map of the "inhabited world" would be by astronomically determining the latitude and longitude of all the principal points on its surface and laying them down in accordance with the positions thus obtained. As the materials for the construction of such a map were almost wholly wanting, and as the means of determining longitude could hardly be said to exist at that early time, the problems he proposed were allowed to slumber for nearly three centuries.

Crates, who lived about 150 B. C., made the first globe in representation of the earth, which maintained itself down into the Middle Ages. Marinus, who lived some time before Ptolemy, was the first to take up and give effect to the problems proposed by Hipparchus for the trustworthy representation of the countries of the world. Ptolemy, who flourished in Alexandria about 139 A.D., in common with all the early philosophers, mathematicians, and geographers from Pythagoras, as well as with the leading contemporaries of his

own time, held the doctrine of the rotundity of the earth, and had some idea of gravity. Availing himself of information acquired and imparted by the master minds of the world who had preceded him, he divided the circumference of the earth and other great circles into 360 parts or degrees, familiarized himself with the theory of projections devised by Hipparchus and others, and, incorporating the work of Marinus, he constructed a network of parallels and meridians, within which he placed the outlines of the world, so far as then known, with a wonderful degree of accuracy considering the resources at his command and the infancy of the science of geography at that time, and with a fair degree of accuracy for those early times determined the absolute distances eastward and westward. In spite of some great errors in his representation of areas, the scientific methods he pursued were perfectly correct, and he was the first to attempt to place the study of geography on a truly scientific basis. His principles and theories dominated the study of geography until gradually superseded and replaced by the progress and results of the maritime discoveries in the fifteenth and sixteenth centuries. As appears from the correspondence with Toscanelli, it was on Ptolemy's map that Columbus based his theories, and it may be truly said that we owe to Ptolemy the art of map-making.

The first requisite of and the fundamental principle underlying all stages of map-making is the determination of the location of the explorer, or the country to be mapped, with reference to the other countries of the earth; to fix its position on the earth with reference to latitude and longitude. Knowing, as we do at the present time, that the earth is, roughly speaking, a sphere that revolves on its axis once in every twenty-four hours, we at once have two points of reference from which we can measure—the ends of the axis of the earth, or the north and south poles. Midway between these two poles, describing the largest possible circle on the earth, we have a line popularly called the Equator, from which all measurements and references north and south are made. For convenience of reference, on either side of this central line at regular distances marking certain degrees of *angular divergence* from the equator, we have what are called parallels of latitude. To these imaginary lines on the surface of the earth can be referred any and every point. Being angular measurements, they have no special distance apart, as measured in miles, until the actual polar diameter of the earth is known. Knowing the size of polar circumference, mathematicians have calculated and reduced the length of a degree to miles. A

degree of latitude is a proportional fractional measurement of the north and south circumference of the earth. They are numbered by the degrees of *angular divergence* beginning at the equator, as zero, and, for convenience, numbering 90 degrees towards either pole.

The axis of the earth infinitely prolonged becomes the pole of the heavens, and where this extended pole is intercepted by a celestial body we have at once the requisite point from which to determine its altitude, or *angular divergence*, from any point on the earth. At the pole it is, of course, at right angles to the horizon, and at an altitude of 90 degrees. In travelling equator-ward in any direction the angle grows less, until at the equator it is on the horizon and has no altitude, so that on the great circle of the earth we have no latitude and must begin there with zero. The altitude, then, of the celestial pole, as measured by the *angular divergence* from the horizon, from any place on the earth's crust, is the latitude of that place. The Pole Star, while coming very near to intercepting the celestial pole, does not do so exactly, and for absolutely accurate results resort must be had to some other and more accurate method. The simplest method, and the one embodied with only slight modifications in all other determinations of this kind, is to measure the highest altitude of any prominent star above the horizon, and by deducting that altitude from 90 degrees you have its angular distance from a point exactly over your head. To this add or subtract, as the case may be, the declination of the star as found in the Nautical Almanac, and the result, after applying corrections for errors due to refraction and other causes, will be the true latitude.

By drawing lines through the 360 divisions or degrees into which the great circle and parallels of latitude have been divided, we have a second and most important system of reference lines, called meridians of longitude, which, together with the parallels of latitude, form a complete network within which to construct a trustworthy and accurate map of the world or any portion of it.

These lines, in common with the parallels of latitude, are not laid down (marked) upon the earth, but are imaginary, and being circular and of equal length, there is no means of determining one from another as a starting-point. This condition necessitates the fixing of an arbitrary zero, and up to only very recent years the principal nations established their respective chief cities as the zero from which was reckoned longitude east and west. England adopted the meridian of Greenwich; France that of Paris; Russia that of Pulkova; Germany that of Ferro, Canary Islands. In America the United States adopted that of Washington, and Mexico

that of its capital city. This multiplicity of zeroes of longitude resulted in so much confusion that the nations of the earth have in recent years come to recognize, and most of them have adopted, the meridian of Greenwich as the zero from which to reckon, east and west, all longitude.

The poles are the ends of the axis on which the earth makes a complete revolution once in every 24 hours. In rotating, every part of it comes opposite a heavenly body—the sun, the moon, or some one of the principal stars—once in each revolution. If an observer can ascertain certainly the *time* of a known star's transit across his meridian he knows his longitude; or if he knows the difference between its time of transit across his meridian and across that of any other station he knows their difference of longitude.

Latitude is the angular divergence north or south from the equator, and longitude is angular divergence measured by the *difference in time* in coming opposite a heavenly body. To observers situated at stations on the same *meridian* (differing in latitude) the heavens present different aspects at *all* moments. The portions of the heavens which become visible in a complete diurnal rotation are not the same, and stars which are visible to both observers describe different circles to their horizons and attain different altitudes. On the other hand, to observers situated on the same *parallel* (differing in longitude) the heavens present the same aspects only at different times. The visible stars describe equal circles to their horizons and attain the same altitude. In the former case a difference in locality is indicated by the appearance of the heavens, while in the latter case there is nothing in the appearance of the heavens to indicate any difference.

Through the recognition of its importance and the elimination of the international jealousies that formerly pervaded the subject, there has come to be recognized, by the leading nations of the world, not only one universal zero of longitude, but the custom as it has come to us from very early times of reckoning 180 degrees east and 180 degrees west of this zero has also become firmly established. As one complete revolution of the earth, of 360 degrees, is counted as twenty-four hours of time, one hour is then equal to 15 degrees, making degrees and their fractions equal to hours, minutes, and seconds in reckoning longitude.

Through the continuous accumulation of information and the gradual development of the subject a constant refinement of positions with reference to latitude and longitude has been going on and constitutes the information from which maps are constructed.

After sufficient information has been accumulated, the next thing in order is that it may be properly represented on a flat surface with the least possible distortion, so as to give the most satisfactory results for the purposes for which the map is to be used. This has been the aim and object of all map-making, and has engaged the attention of the leading mathematicians since the time of Ptolemy.

As the earth is a sphere, and its surface is curved, to spread out on a plane, without breaking or distorting, a spherical or curved surface is impossible, so that a perfect map is from the very nature of the case impossible to construct. In any effort in this direction there is distortion and disproportion of areas as a result. In their efforts to overcome these difficulties, to remove or minimize the effect of these errors, mathematicians and geographers from Ptolemy's time to the present have devised many forms of projection for the representation of the positions, shape, and configuration of portions of the earth, and each form may be said to fill its place in the map world. As the conditions differ for which particular projections are necessary, it frequently happens that different methods of treatment for the various cases become necessary, and for this reason no general theory underlying the whole subject of projections can be given.

In the absence of the possibility of a perfect map, the efforts of cartographers have been directed towards the production of maps in which all errors should be as nearly as possible eliminated, or such maps as would be best adapted for some special purpose.

In the development of the subject I hope to show clearly that if a map represents areas exactly, or free from distortion, or shows any line on the sphere at its proper angle with the meridians, one at least of the other objections, either in distortion or proportion, must be admitted. For navigating purposes, where angular accuracy is required, the necessities of the case must govern, admitting of no compromise with any other consideration. For general purposes, however, in the mapping of land surfaces in particular, the most suitable are those in which all the errors of distortion and disproportion are present, but by reducing both to a minimum a fairly good representation of portions of the earth's surface is obtained.

It is this projection or conventional representation of the curved surface of the earth with as little distortion and disproportion as possible on a flat surface that is the very foundation of map-making. In projecting a map regard must be had to the purpose for which the map is intended, as well as to the area it is to represent.

The errors in one form of projection being imperceptible in small areas or in areas near the equator would so distort and exaggerate large areas or more northern countries as to be fatal to its use. In the early days of geographic knowledge, when the general belief was that the earth was a flat disc surrounded by the sea, the maps that have come down to us plainly show in their construction the limited horizon of the peoples of the earth. As the range of vision widened through trade and travel, the horizon was extended, until eventually the true shape of the earth dawned on the minds of men and was reflected in the change that this knowledge made necessary in the mapping of the world. The Chaldaean shepherd, the Egyptian soothsayer, and the primeval priest, in common with the earlier Oriental astrologers, were probably first attracted by the celestial bodies as striking features of the cosmos. Later they were led through observation to note their rhythmic process with greater care, and cycles were established and eclipses and other phenomena were foretold long before the true structure of the solar system was introduced. Leading up from and through these early forerunners of the two great sciences of astronomy and geography, we come to a stage in their development where the accumulation of knowledge had extended the horizon far beyond the confines of the individual locality of the tribe or nation to the recognition of the vastness of the earth and the rotundity of its surface. Pythagoras, Hipparchus, Marinus, and Ptolemy stand out in bold relief as the pioneers who shaped the course of the advance of geographic knowledge and laid the foundations for map-making. From the early conception of the rotundity of the earth, through the different stages as represented progressively by these great minds, the representation of the earth began to assume new forms. In the final recognition of the earth as a sphere a new element forced its way into the construction of maps, until a clear understanding of the changes resulting in a continuous improvement in the method of correctly showing on a plane surface distances, direction, and configuration of any portion of the earth has been the result.

The name projection, as implied by the term, was derived from geometers, and was originally confined to representations obtained directly according to the laws of perspective. It has, however, through a long and gradual series of developments, come to signify any method of representation of the surface of the earth upon a plane. The ancients, in their attempts at representing the heavens and the areas of the earth's surface, were familiar with and employed

only the perspective forms which depended upon the supposed position of the spectator's eye, and on that of the plane of projection, and may be included under three heads.

The *orthographic* projection (Fig. 1) supposed the eye at an indefinite distance, and the plane of projection perpendicular to the line of sight, situated anywhere on that line. A map produced on this projection represents the areas at the edge as indefinitely small and very greatly distorted, and is well suited to maps of the moon.

The *stereographic* projection (Fig. 2) supposed the eye upon the surface of a sphere occupying the pole of a great circle, with the plane, which is that of the projection, bisecting this diameter at right angles.

The *gnomonic*, or central projection (Fig. 3), supposed the eye at the centre of the sphere and the plane of projection tangent to its surface.

FIG. 1.

Orthographic Projection on the Plane of a Meridian

In their application to astronomy and geography these forms are rarely if ever applied to small areas, but are usually confined to the representation of a hemisphere. It is only as we approach more modern times, however, after the subject has passed through and been worked over by the master minds of past ages, that we have reached the stage of map construction by so-called development. By substituting for the actual surface of the sphere a cylindric or conic surface, the great difficulty of the impossibility of representing the spherical surface on a plane is partially overcome by developing these forms in a plane. As a result of these methods we have projections developed along two different lines—those employing a cone tangent, generally at the middle parallel, and those employing a cylinder tangent, generally at the equator.

If a comparatively small region is to be projected, the operation will be rendered quite simple by substituting for the actual surface a cone passed tangent to the sphere along the parallel of latitude, which is at the middle of the region to be projected. By developing the cone (Fig. 4) upon a plane, the meridians will become right lines from the vertex of the cone to the different points of the parallel of tangency, and the parallels will be concentric circles, with the vertex of the cone as the common centre. Along the central parallel the areas will be equal to those on the sphere; but as the distance from the point of tangency increases, the distortion grows, and areas are shown larger than on the sphere.

FIG. 2.

Stereographic Projection

on the Plane of a Meridian

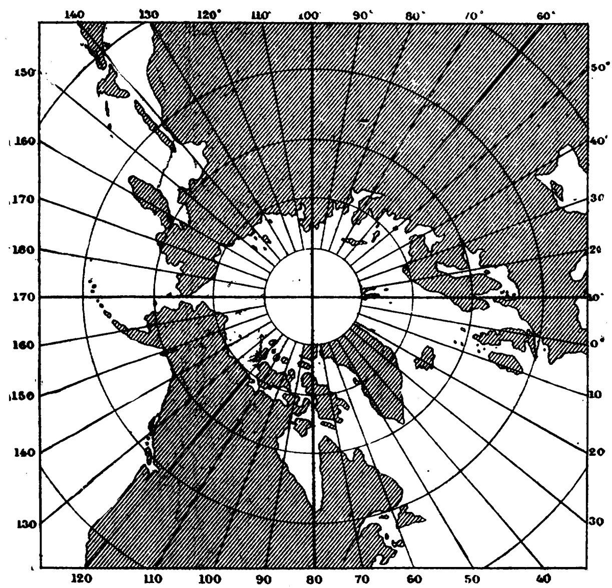
Mercator's projection (Fig. 5) is the one most used in the construction of sailing charts. It is also especially adapted for representing the earth as a whole and for mapping areas in the equatorial region. A cylinder tangent at the equator, with an axis coincident with that of the sphere, is cut by the meridians and parallels. The meridians will be represented upon the cylinder by right lines and the parallels by circles, the right sections of the cylinder. By developing the cylinder we obtain a projection in which both meridians and parallels are represented by right lines at right angles to each other. Between the meridians the distance is at all points the same, but the underlying principle on which this projection is based is that each element of latitude is increased in the same ratio as the longitude, producing an exaggeration in the areas, but no distortion. The Mercator's projection gives correctness of outline and of direction, and for nautical purposes, for which it was designed, is of the

greatest importance. A curved line, drawn upon the surface of a sphere in such a manner as to cut all the meridians at the same angle, is represented on the Mercator's projection as a straight line. (Figs. 4 and 5.) The meridians in Mercator's projection being parallel, a straight line would cut any number of them at the same angle; and as the longitude and latitude at every point are increased in the same proportion, the angle this straight line makes with the meridians is the angle the curved line makes with the meridians on the sphere. In navigation, by laying down a straight line between two ports, the

FIG. 3.

Gnomonic Projection

Plane tangent at the Pole



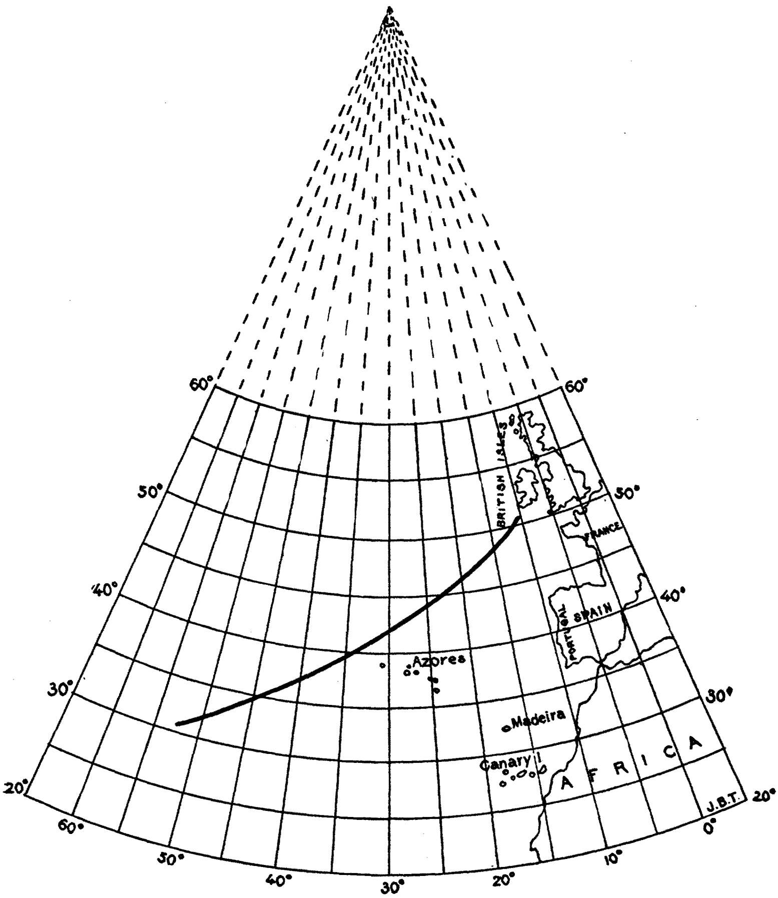
navigator is enabled to read all of his bearings on the maps. The want of uniformity of scale of distances is its great defect; but as it is of greater importance for a navigator to know his direction or course than to know his distance, this defect is overcome by the ease with which distances can be calculated.

By combining or varying the principles of these forms (Fig. 6) a great variety of this class of projection by development can be produced. The one leading to a reduction of the distortion, that is

always present in reducing from a spherical to a plane surface, is produced by substituting an intersecting for a tangent cone, in order that it may conform to the condition that areas of spherical zones should in their projection bear the same proportion as the corresponding areas on the sphere.

FIG. 4.

CONICAL PROJECTION.



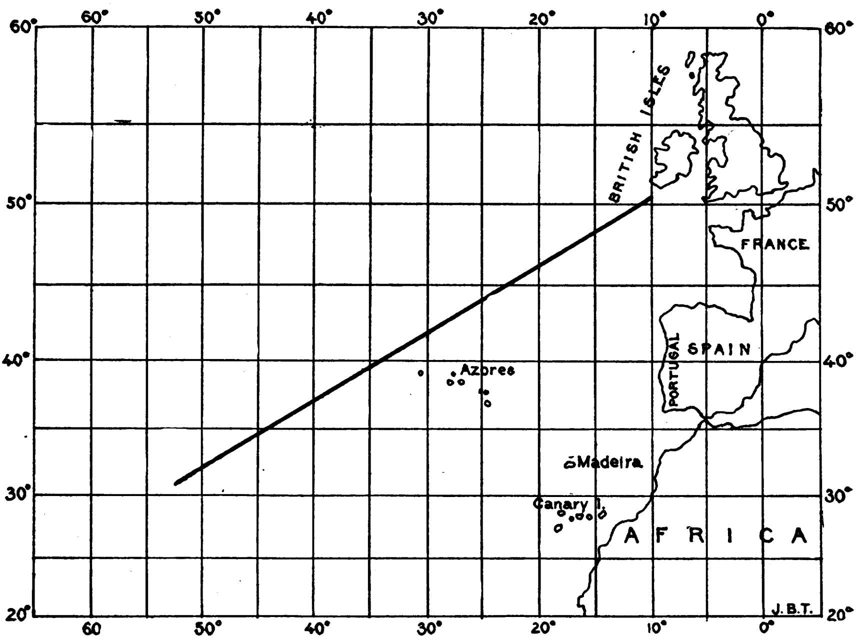
The polyconic, or that projection which is an assemblage of sections of surfaces of successive cones, tangent to or cutting a regular succession of parallels, and upon regularly changing central meridians (Fig. 7), may be said to have originated in conception with the

superintendent of the U. S. Coast Survey, F. R. Hassler, between 1816 and 1820.*

Supposing each parallel of latitude to be developed upon its own cone, the vertex of which is on the axis, at its intersection with the

FIG. 5.

MERCATOR'S PROJECTION.



tangent to the meridian at the parallel, instead of one tangent cone being used there is one for every parallel, and, theoretically, an infinite number. As each parallel of latitude is independently developed, the effect is of gradually increasing the length of the degree of latitude in proportion as we recede from the central meridian, upon which only they are correct.

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* To show the difference between the Cylindric, the Conic, and the Polyconic projections :

The CYLINDRIC (Mercator's) is projected to the cylinder A, tangent at the Equator. The CONIC is projected to any one of the cones B, which are to be tangent at the middle latitude. The POLYCONIC is projected on the cones B,B,B, each tangent to successive parallels.

(Lieut. John E. Pillsbury, U. S. Naval Inst., Proceedings Vol. X.)

Through the similarity to the angles of intersection of meridians and parallels, which nowhere differ greatly from right angles, the

FIG. 6.

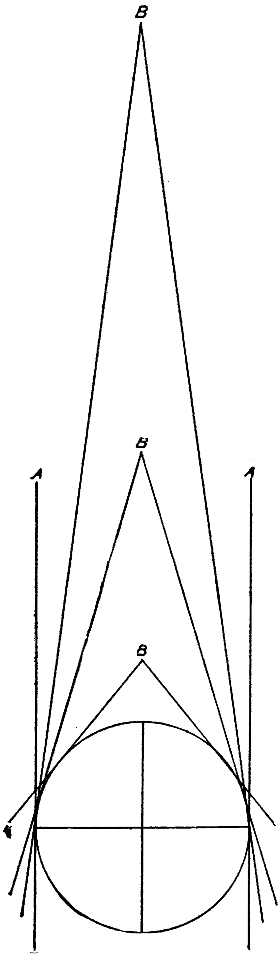
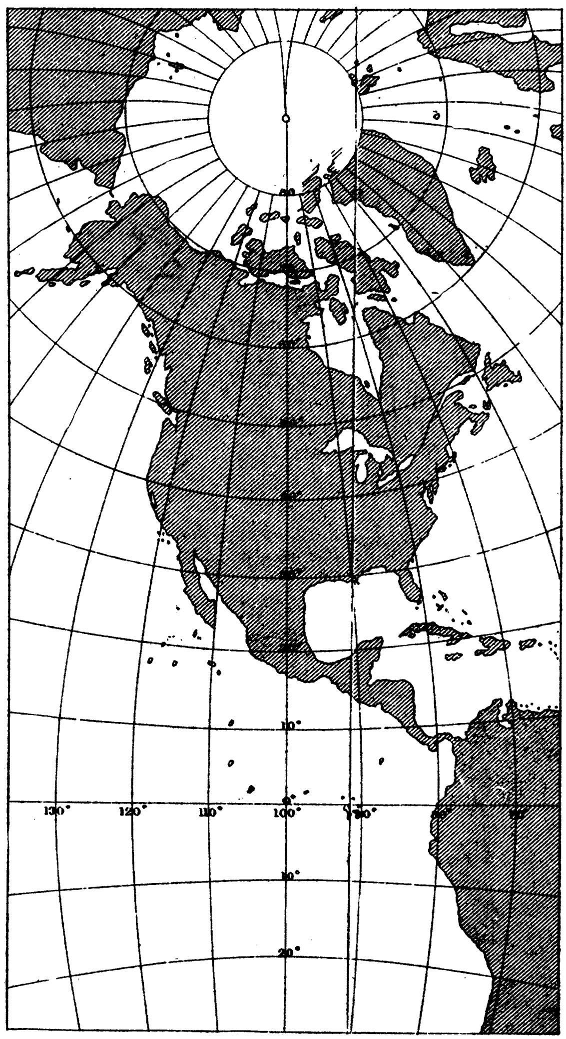


FIG. 7.

Polyconic Projection



figures on the sphere and the corresponding ones on the projection are very close. The parallels are divided into the same proportional parts as on the sphere, and are degrees, minutes, or seconds of lon-

gitude. While the exact proportion of corresponding areas on the sphere and the projection is not maintained, the same linear scale can be applied to all parts of a chart of limited extent, and distortion of areas is reduced to a minimum. The scale throughout is in exact proportion to the corresponding areas of the surface of the earth: a scale of $\frac{1}{63360}$ means that one inch of paper equals 63,360 inches of the earth's surface, or one mile of the earth's surface is equal to one inch on the paper.

The early pioneers of geographic knowledge laid the foundations of map making with such thoroughness that the superstructure, as we know it to-day, is built upon their work as a base. The information of configuration and relative positions and distances of the earth's surface, as it has been accumulated and systematized, has been developed on a plane surface, according to well-defined schemes of projection, that have gradually and successfully tended towards lessening the distortion and disproportion, until very satisfactory results have been obtained for the many different purposes for which maps are used. From a limited horizon and perspective projection of early times we have reached, in this day of enlightenment, a very comprehensive view of the earth as a sphere, and the representation of its surface in such wise as to produce the least possible distortion and disproportion of areas.